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PM AND CO_2 VARIABILITY AND RELATIONSHIP IN DIFFERENT SCHOOL ENVIRONMENTS

Article Highlights

- Diurnal variation of PM, CO_2 and NO_2 in classroom
- PM, CO_2 and NO_2 concentrations during heating and non-heating period
- Strong correlation between PM and carbon dioxide CO_2 concentrations
- Management strategy for controlling of PM and CO_2 levels inside the schools is needed

Abstract

Indoor air quality (IAQ) is very important for children health and well-being, since children are particularly vulnerable and sensitive to the presence of air pollutants. This study was performed in two naturally ventilated schools located in the same municipality. The first school is located in an urban area, at a residential-industrial site, while the other school is situated in a rural area. School buildings were chosen based on their urban environment features. The measurements were carried out in heating and non-heating periods in duration of five consecutive working days. The objective of the study was to analyze IAQ in the classrooms with special emphasis on levels and diurnal variations of particulate matter (PM_{10} and $PM_{2.5}$), carbon dioxide (CO_2) and nitrogen dioxide (NO_2) in occupied and unoccupied school classrooms. In this paper, the CO_2 concentrations were measured at both indoor and outdoor environments. Concentrations of CO_2 higher than 1000 ppm were regularly detected in the classrooms during teaching hours. Indoor concentrations of PM_{10} were not exceeded the guideline, daily average, value of 50 μg/m^3. Concentrations of $PM_{2.5}$ exceeded the guideline daily average value of 25 μg/m^3 in both school during heating period. Concentrations of NO_2 did not exceed the guideline value of 200 μg/m^3. Ventilation rates were calculated and compared with the prescribed limits. In both occupied and unoccupied periods high correlation between CO_2 and PM concentrations was determined.

Keywords: indoor air quality (IAQ), particulate matter, carbon dioxide, nitrogen dioxide.

In recent years, IAQ became a widely recognized issue that attracts researchers and public attention towards improving the air quality [1-5]. Public concern over IAQ has dramatically increased, as hundreds of pollutants from various indoor and outdoor sources have been identified in indoor environments. IAQ is defined as human need to perceive fresh and pleasant air with no negative impacts on their health and productivity and it is especially important in schools in order to enhance children's learning ability and their performance [6].

The primary purpose of schools buildings and facilities is to provide children with healthy and satisfactory places for their learning and development. Total working capacity of children decreases with illnesses and absence from school [7,8]. School buildings are complex spaces to design as they need to perform well in all aspects of environmental conditions, during accommodating periods with very high occupant densities. The typical classroom has on

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average four times as many occupants per square meter as the typical office building [9].

Air quality is of the great importance for children health as children are particularly vulnerable and sensitive to presence of pollutants in ambient air. The typical indoor air pollution sources in school buildings are different: outdoor air pollution, emissions from building materials, paints, varnishes, solvents, combustions products of fuel combustion for heating, etc. The indoor level of air pollutants depends on: ventilation, number of children in classrooms and their activities, lessons durations, breaks between lessons. In winter ventilation in the school classrooms is usually limited. That contributes to increase in levels of CO_2 and other air pollutants. Other than at home, children spend most of their time indoors while they are at school. At this developmental stage in their lives, children are vulnerable to a range of environmental exposures that may contribute to long-term adverse effects. Since different research groups have different approach to the study of IAQ, many of them attach great significance to CO_2 concentration in buildings. There is an abundance of studies showing high contamination levels of carbon dioxide in classrooms [2,4,10-17]. The rate at which the humans produce CO_2 varies mainly with the duration and intensity of physical activity. The level of indoor CO_2 has become widely used as one of indicator of IAQ and surrogate for the ventilation rate measurements. Ventilation rates greatly influences to IAQ. Low ventilation rate influence to adverse health effects, impaired attention span, concentration loss and tiredness to children [1,18-20]. According to Serbian standards [21], category II is recommended for school buildings, 7 l/s per person. By the ASHRAE standard, the lowest ventilation rate is 8 l/s per person and recommended ventilation rate is 10 l/s [22].

Particulate matter (PM) is a complex mixture of extremely small particles and liquid droplets. It is well known that a number of health problems have been associated with high concentrations of PM [23]. Exposure to PM of indoor air has been linked to many different diseases, including acute and chronic respiratory diseases, tuberculosis, heart disease, asthma, lung cancer, cardiovascular disease and perinatal health outcomes. Several studies have recently been published concerning the PM [24-33] and NO_2 [30-32] levels in classrooms all over the world. Young children are the most vulnerable population group considering the fact that they spend a large proportion of their time indoors [34]. Exposure to fine particles, less than 2.5 μm in diameter, poses a great risk particularly to people with heart or lung diseases and older adults [35]. Inhalation of fine PM has been linked to increases in respiratory health problems (asthma, bronchitis, etc.). PM levels in indoor environment are under influence of PM levels in ambient air. Also, PM content indoors sometimes can be more toxic than outdoors. Pollutant levels from individual sources may not pose a significant health risk by themselves; usually school buildings have more than one source that contributes to indoor air pollution. Additionally, indoor temperature, humidity and ventilation may be the reasons for the increased generation of air pollutants.

The objective of our study was to analyze the indoor air quality in the classrooms with special emphasis on PM and CO_2, diurnal variations, ventilation rates and correlations in occupied and unoccupied indoor environment. Thus, relationships between PM fractions, CO_2 and NO_2 in two primary schools located in the same municipality were investigated.

EXPERIMENTAL

Measurements were performed in two naturally ventilated schools located in the same municipality. The first school (school A) is located at aresidental-industial site and the second (school B) is situated in a village area with a low population density. The distance between the schools is about 15 km. School A, is located in an industrial town with the population of around 40,000 inhabitants. The main characteristic of this town is the high percentage of households connected to district heating system (more than 95%). The main feature of the housing stock is that it mainly consists of buildings, rather than individual houses. School B is situated in a village. The main feature of the housing stock is that it consists of individual houses with individual heating systems. Two sampling campaigns, each in duration of five consecutive working days (from Monday morning to Friday evening), were performed during winter, in heating period and during spring, in non-heating period. The schools are different with respect to age, construction and size. School A, located in the urban area, was built in the 1970s. However, school B, located in the rural area, is more than 100 years older than school A, and has not been renewed for a long time. School A is connected to the district heating systems, while school B has its own heating system. Classrooms with the similar features were selected, occupied by the children from 7 to 10 years old. Numbers of occupants in the selected classrooms were 17 (about 3 m^2/per person) in school A and 28 (about 2 m^2/per person), in school B. Classrooms in both schools were naturally ventilated as usual and were cleaned by wet wiping every day, in school A twice a day, before every shift, and in school B once, in the morning shift.

Sampling equipment

PM levels were monitored with the portable direct reading airborne particle monitor OSIRIS (model 2315), that provides continuous real-time readings of TSP, PM_{10}, $PM_{2.5}$ and PM_1 particulate mass fractions. It uses a light scattering technique to determine the concentration of airborne dust in the particle size range from 0.4 to 20 µm. The incoming aerosol passes through a laser beam in a photometer, and then through a filter which removes particles before reaching the pump. In this study we use PM_{10} and $PM_{2.5}$ fractions. Simultaneously with the OSIRIS, 24-h sampling of indoor (I) as well as outdoor (O) PM was carried out using a low volume sample LVS reference sampler (Sven/Lackel LVS3) with PM_{10} and $PM_{2,5}$ standard inlets. The sampling flow rate of LVS was 2.3 m^3/h. Quartz fiber filters (Whatman QMA, 47 mm) were used. The filters were conditioned for at least 48 h before weighing and weighed according to SRPS EN 12341:2008. The filters were measured at room temperatures of 20 °C and humidity of 50%. The OSIRIS PM readings were corrected with calibration factor calculated by comparing the 24-h average levels of PM with those obtained by reference gravimetry method [36].

CO_2 concentrations, temperature and relative humidity were measured every 10 min using the Testo 435 devices and IAQ probe, with the CO_2 precision of ±50 ppm, range 0-5000 ppm, temperature precision ±0.3 °C, range 0-50 °C and RH precision of ±2% and range 2-98%. The equipment was calibrated at the beginning of each measurement campaign. The position of sampling devices and measuring equipment in the classroom was opposite to the blackboard, about one meter above floor level, the level at which the pupils would normally inhale. This location inside the classroom was chosen as a typical and it being away from the door, thus avoiding disturbances resulting from air streams.

Radiello diffusive samplers were used for indicative measurement of indoor and outdoor concentrations of nitrogen dioxide (NO_2) during a 5-day period of continuous monitoring in each school. This diffusive sampler is a closed cylindrical box with two opposite sides, one is transparent to gaseous molecules which cross it, and are adsorbed onto the second side. Driven by the concentration gradient, the gaseous molecules pass through the diffusive surface and are trapped from the adsorbing surface. The sampling rate value Q varies with temperature following the equation:

$$Q = Q_{298}(T/298)^7 \tag{1}$$

Equation (1) is valid for the temperature range from -10 to 40 °C. In the Eq. (1) is the sampling rate at 298 K (25 °C) is marked as Q_{298} that is equal to 78 ml/min at 1013 hPa. Nitrite is quantified by visible spectrophotometry. Limit of quantitation was 1 ppb [37].

During the sampling campaigns, the OSIRIS was moved to several places in the school (usually after 2 days of measurements at one classroom) to keep track of diurnal changes in PM concentrations. CO_2 and NO_2 were collected at four measuring points simultaneously, in three classrooms and outside the school.

Methods

In this study we assume that air in the classrooms is well mixed. The classrooms are naturally ventilated which is common for majority of public buildings. CO_2 concentration in the classroom at the beginning of the lesson is notified as C_o. The CO_2 level in the classroom increase during the lesson more or less intensively. The CO_2 level in the inflow air is notified as C_v and in the outflow air as C. Uniform distribution of CO_2 in the classrooms is assumed. For mechanically ventilated as well as for well mixed naturally ventilated spaces, the mass balance of CO_2 concentration can be expressed as [38,39]:

$$Gdt + QC_v dt - QCdt - VdC = 0 \tag{2}$$

From Eq. (2) it is:

$$dC = -d\left(\frac{G}{Q} + C_v - C\right) \tag{3}$$

By the integration of Eq. (2) we obtained the following formula for the determination of CO_2 concentration change in the classroom:

$$C = C_v + \frac{G}{Q} - \left(C_v + \frac{G}{Q} - C_0\right)\left(e^{-\frac{Q}{V}t}\right) \tag{4}$$

where G - CO_2 generation in the classroom, Q - air volume flow rate, V - room volume, and t - time.

In order to estimate the air change with the least possible parameters it is assumed that the classroom is unoccupied, $G = 0$. Thus, Eq. (4) can be rearranged to give the following:

$$Q = -\frac{V}{t}\ln\left(\frac{C - C_v}{C_0 - C_v}\right) \tag{5}$$

RESULTS AND DISCUSSION

Table 1 presents average values and ranges of CO_2, *RH*, T, PM_{10}, $PM_{2.5}$ and NO_2 for both schools in heating and non-heating period. In heating period, daily average CO_2 concentrations were higher in school located in rural area then in school in urban area, whilst there were no such differences in non-heating period. During the campaign in heating period, due to low temperature (about -14 °C), lessons were shortened from 45 to 30 min. This shortening could contribute to overall lowering of CO_2 levels in heating period.

Significant periodical variations of PM concentrations were observed with higher levels during heating period in both schools. The indoor PM concentrations were higher in school located in rural area then in school in urban area in both sampling periods, especially in heating period. This is probably a result of resuspension of particles from floors. The indoor concentrations of NO_2 were generally lower in school B than in school A, but the outdoor concentrations were higher at school B. The reason for this phenomenon was extremely low temperature in heating period in school A and the temperature dependence of the sampling rate, which must be in the range from -10 to 40 °C. This was also the reason why the concentration of NO_2 in heating season in outdoor environment near school A was uncertain. The measurement campaign in non-heating at school A was during rainy which can be the main reason why the indoor NO_2 concentrations were higher than outdoor [37].

In the recent years, several studies about IAQ in school environment have been published. PM, CO_2 and NO_2 concentrations in studies similar to our study are shown in Table 2. CO_2 measurements in this study at school A in non-heating and at school B in both periods were similar with studies from Table 2. The results for school A in heating period was similar with those obtained at [14] but lower than in the other studies presented in Table 2. Concentrations of $PM_{2.5}$ are in line with findings of previous studies. Concentrations of PM_{10} and NO_2 in both schools are lower than the concentrations in schools presented in Table 2.

Indoor concentrations of PM_{10} were not exceeded the guideline, daily average, value of 50 μg/m^3 [40] in both school during heating and non-heating period. An outdoor concentration of PM10, for school A in heating period is higher than 50 μg/m^3. Concentrations of $PM_{2.5}$ were exceeded the guideline daily average value of 25 μg/m^3 [40] in both school during heating period. Concentrations NO_2 were not exceeded the guideline value of 200 μg/m^3 [40]. Concentrations of CO_2 for all periods of measurement in school B is higher than recommended values, while during lessons and break, occupied period, concentrations of CO_2 usually exceeded recommended values [21,22,41].

Figures 1 and 2 show that during school day, PM and CO_2 concentrations increased when pupils enter the classroom, and reaches their maximums at the end of the morning shift. Then, during a break between shifts, the concentration of CO_2 decreases, while in some classrooms PM concentration increases. With the start of afternoon classes in school A, PM and CO_2 concentrations begin to rise again. At

Table 1. Averages and ranges of CO_2 (ppm), RH (%), T (°C), PM_{10} (μg/m^3), $PM_{2.5}$ (μg/m^3) and NO_2 (μg/m^3) for heating and non-heating period, in schools in urban and rural area

Parameter		School-period							
		A-heating		B-heating		A-non heating		B-non heating	
		Average	Range	Average	Range	Average	Range	Average	Range
CO_2	I	812	449-2259	1305	475-4520	767	321-2011	973	407-2981
	O	424	400-449	524	n/a	524	412-1011	583	381-1099
RH	I	27.7	20.2-53.9	46.4	34.6-58.3	54.0	42.7-72.7	68.1	56.4-80.1
	O	77.6	64.0-84.4	69.8	47.5-75.9	72.7	51.2-93.3	72.7	54.6-85.9
T	I	14.0	8.1-20.3	15.3	10.7-21.6	19.8	17.5-22.5	21.3	19.0-26.1
	O	-13.6	-16.8--8.0	0.2	-4.7-7.3	12.9	8.5-20.2	18.3	14.5-23.1
PM_{10}[a]	I	44.21	37.07-57.02	49.35	38.38-69.64	42.31	37.68-48.83	21.14	14.13-25.01
	O	54.74	44.24-76.18	38.28	34.65-62.01	16.15	9.77-24.35	35.32	30.72-82.49
$PM_{2.5}$[a]	I	25.16	14.00-26.41	28.59	15.21-47.07	12.73	8.47-19.39	17.76	10.88-22.69
	O	45.87	33.81-80.54	32.97	11.53-62.13	13.37	4.98-17.68	15.58	3.97-25.64
NO_2	I	12.58	n/a	7.69	n/a	8.85	n/a	6.44	n/a
	O	6.49	n/a	12.54	n/a	3.70	n/a	9.91	n/a

[a]Measured by gravimetric method

Table 2. Comparison of CO_2 (ppm), PM_{10} (μg/m^{-3}), $PM_{2.5}$ (μg/m^{-3}), NO_2 (μg/m^{-3}) with concentrations measured in this study; H - heating period, NH - non-heating period

Number of schools (environments)	Season	Parameter	Average (Range)		Reference
			Indoor	Outdoor	
1 (urban)	H	CO_2	1288 (/-2585)		Mumovic *et al.* [2]
1 (rural)	H	CO_2	1007 (/-1857)		
1 (urban)	H	CO_2	1042 (/-2100)		Heudorf *et al.* [3]
		PM_{10}	62 (38-105)	37 (15-73)	
1 (rural)	H	CO_2	1820 (/-4840)		
		PM_{10}	75 (35-150)	15 (10-20)	
5 (urban)	H	CO_2	> 1000		Lee *et al.* [12]
		PM_{10}	(21 -617)		
		NO_2	(12-176)	(19-244)	
9 (urban)	NH	CO_2	837 (398-3279)	~370	Godwin *et al.* [13]
3 (urban)	H / NH	CO_2	> 1800		Almeida *et al.* [14]
		PM_{10}	(30-146)	(8-47)	
		$PM_{2.5}$	10	(3-10)	
4 (urban)	H	CO_2	834 (704-1042)		Habil *et al.* [15]
		PM_{10}	395.66 (236.55-677.00)		
		$PM_{2.5}$	285.91 (100.00-475.86)		
	NH	CO_2	530 (466-667)		
		PM_{10}	298.41 (218-542)		
		$PM_{2.5}$	229.16 (110.00-421.00)		
14 (urban)	NH	CO_2	(705-6821)		Pegas [16]
		NO_2	30.1	38.8	
3 (urban)	H	CO_2	> 1000		Pegas [17]
		NO_2	37.9	49.8	
64 (urban / rural)	H	CO_2	1759 (598-4172)	414 (381-490)	Fromme *et al.* [24]
		PM_{10}	105.0 (16.3-313.2)		
		$PM_{2.5}$	23.0 (2.7-80.8)		
	NH	CO_2	892 (480-1875)	391 (338-509)	
		PM_{10}	71.7 (18.3-178.4)		
		$PM_{2.5}$	13.5 (4.6-34.8)		
24	NH	$PM_{2.5}$	23.0 (7.7-52.8)	24.8 (5.2-60.8)	Janssen *et al.* [27]
		NO_2	19.1 (2.8-44.7)	39.2 (10.7-76.6)	
27 (urban / suburban)	H / NH	$PM_{2.5}$	61 (11-166)	51 (13-149)	Stranger *et al.* [28]
		NO_2	57 (14-159)	63.7 (27-147)	
7 (urban)	H	PM_{10}	236.13 (74.65-668.74)	162.89 (49.25-401.12)	Diapouli [30]
		$PM_{2.5}$	82.65 (22.06-198.58)	56.25 (23.32-99.00)	
4 (urban)	H / NH	PM_{10}	38.4 (4.6-166.9)	53.4 (5.9-237.4)	Raysoni *et al.* [33]
		$PM_{2.5}$	17.0 (1.5-104.3)	20.9 (1.2-130.4)	
		NO_2	37.4 (1.2-328.3)	16.1 (1.7-50.4)	

the end of the school day, both PM and CO_2 concentrations start to decrease. The high concentrations of PM and CO_2 were observed in the time periods when the children were at school. The increased PM concentrations during teaching hours and their correlation with high CO_2 concentrations indicate that inadequate ventilation plays a major role in the establishment of poor indoor air quality in the observed schools.

Figures 3 and 4 present average concentrations of particulate matter $PM_{2.5}$ for occupied periods in both schools obtained by reference gravimetric method. The measurements revealed considerable differences and relationships not only between indoor and outdoor air qualities in two schools, but also between indoor $PM_{2.5}$ concentrations in different classrooms in the same school. The variability of $PM_{2.5}$

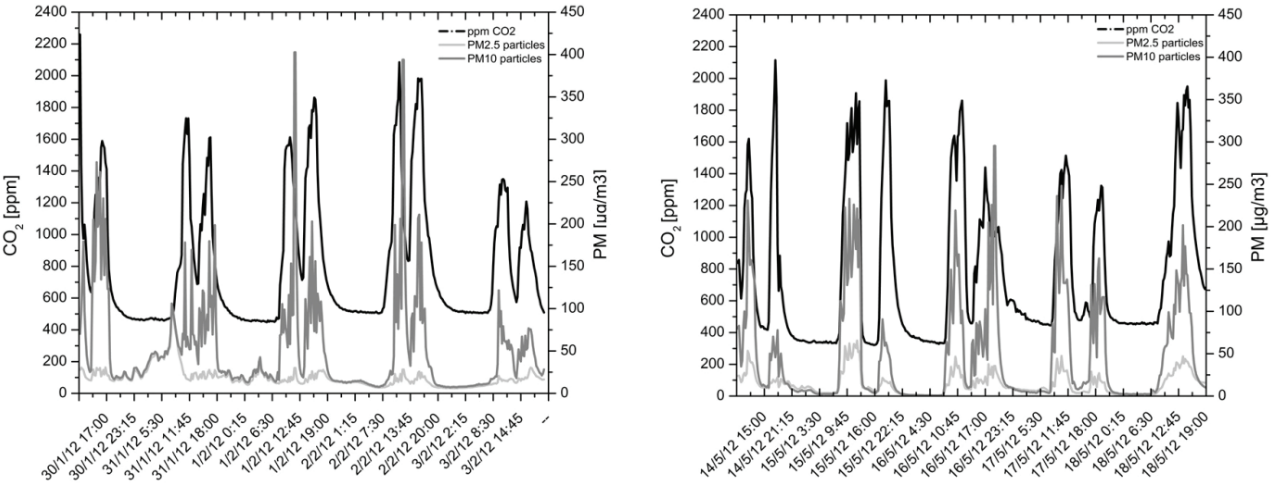

Figure 1. Change of CO_2, $PM_{2.5}$ and PM_{10} in the classrooms, school in urban area, one week campaign, in heating and non-heating period.

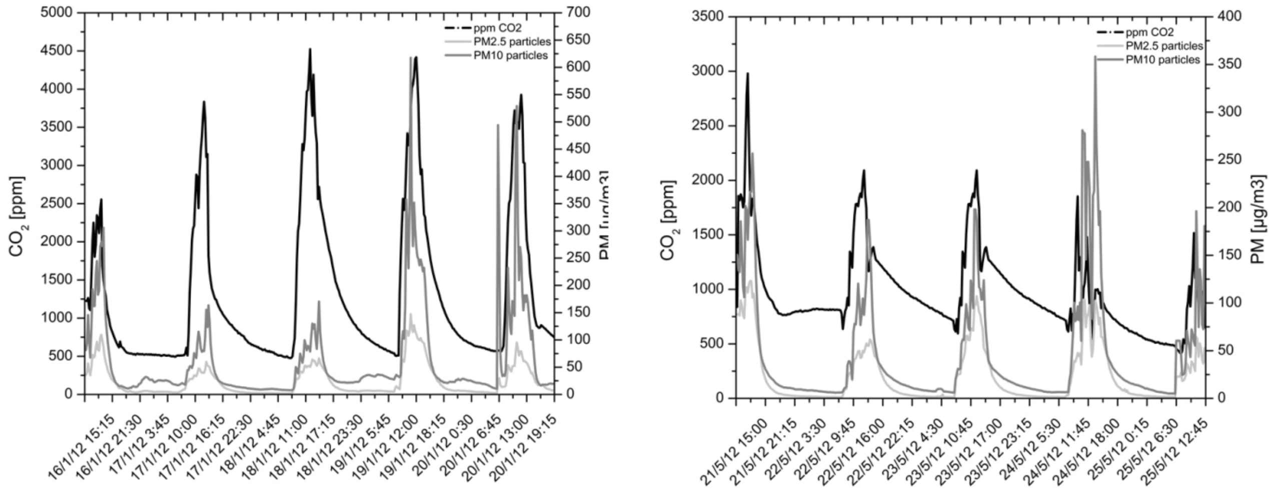

Figure 2. Change of CO_2, $PM_{2.5}$ and PM_{10} in the classrooms, school in rural area, one week campaign, in heating and non-heating period.

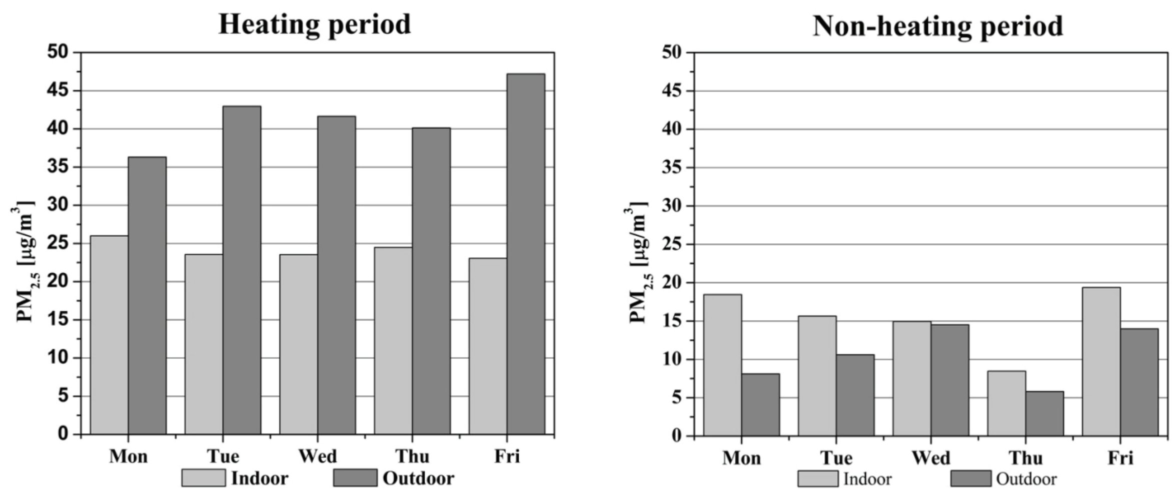

Figure 3. Daily indoor and outdoor concentration of $PM_{2.5}$ for occupied period, school A.

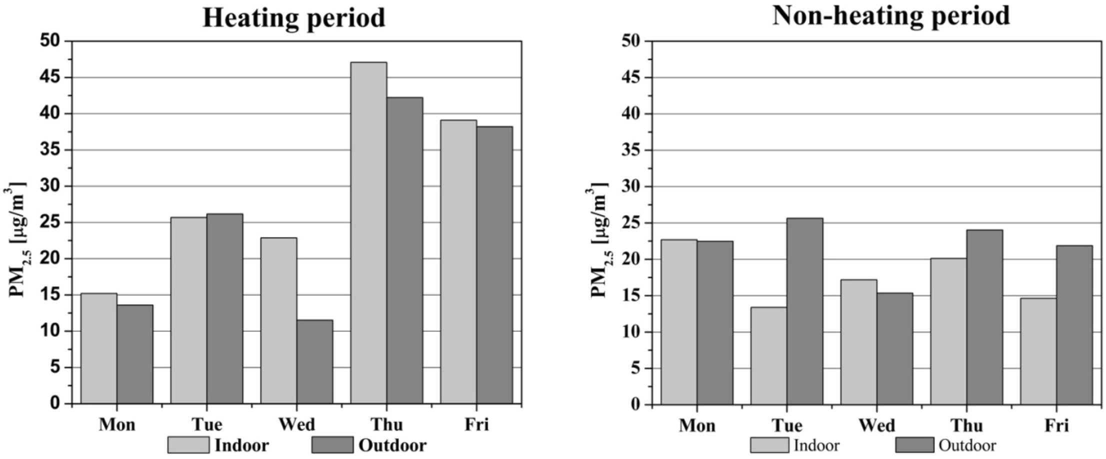

Figure 4. Daily indoor and outdoor concentration of $PM_{2.5}$ for occupied period, school B.

concentrations in winter and spring season is most likely due to the different ventilation practices in heating and non-heating period. Because of increased ventilation in the non-heating period, the indoor concentrations of $PM_{2.5}$ were strongly dependent on outdoor $PM_{2.5}$ levels. In heating period $PM_{2.5}$ concentrations were more strongly influenced by indoor activities. During heating period, when children were in classrooms, indoor concentration of $PM_{2.5}$ was higher in school A. During non-heating period concentrations of $PM_{2.5}$ were higher in the school located in rural area, school B. The reasons for such elevated indoor concentration of $PM_{2.5}$ were outdoor sources such as burning fossil fuels.

Table 3 presents daily indoor to outdoor (I/O) $PM_{2.5}$ concentration ratios in the schools when the children were in the classrooms. I/O $PM_{2.5}$ ratio for heating period at school A was less than 1 while for non-heating period was above 1. The I/O $PM_{2.5}$ ratios for school B were found close to 1 for both periods.

Table 3. Daily I/O ratio for $PM_{2.5}$ (μg/m^3) for occupied period, in schools A and B

Weekday	School A		School B	
	H (I/O)	NH (I/O)	H (I/O)	NH (I/O)
Monday	0.72	2.27	1.12	1.01
Tuesday	0.55	1.48	0.98	0.52
Wednesday	0.57	1.03	1.98	1.12
Thursday	0.61	1.46	1.11	0.84
Friday	0.49	1.39	1.02	0.67

Calculation of the average air exchange rates (*Q*) for chosen schools based on attenuation of CO_2 concentration has been performed using Eq. (5) and measurement data for the unoccupied period in selected classrooms. Figure 5 shows the attenuation of indoor CO_2 concentration in unoccupied period. Volumes of the observed classrooms, average number of occupants and ventilation rates are shown in Table 4. The values of ventilation rates were lower than recommended values for school classrooms.

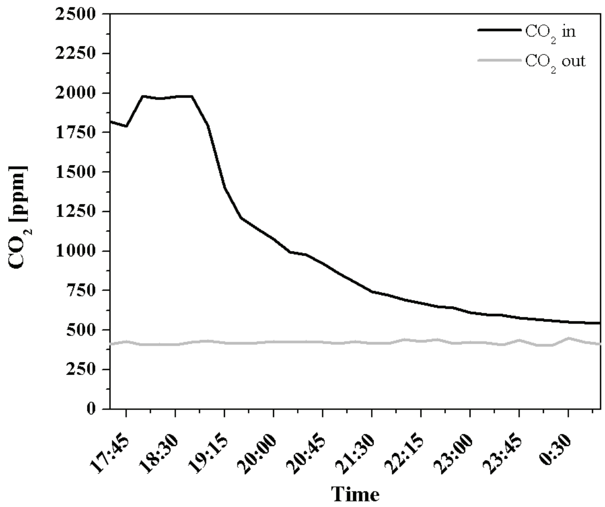

Figure 5. CO_2 concentration measured in unoccupied period.

Table 4. Ventilation rates in schools (H - heating period, NH - non-heating period)

Class	School A		School B	
	H	NH	H	NH
1	2.95	7.70	1.51	1.90
2	1.50	2.78	1.85	1.62
3	3.43	5.21	1.06	6.00

Correlation

The correlation between PM and CO_2 concentrations was calculated for all period of measurement and for the period when classrooms were occupied. During the measurement campaigns in the school A, the average outdoor temperature was about -14 °C for the heating period and 14 °C for the non-heating period. The average outdoor temperature was 1 °C for heating period and 20 °C for the non-heating period during measurement campaigns perform in school B. Table 5 presents correlation coefficients between PM and CO_2 concentrations during periods when the classrooms were occupied and for all period of measurements. High correlations between the PM and CO_2 concentrations were detected in both schools in the non-heating period. For school A, during heating season under extremely low temperature conditions, correlation was high only between PM_{10} and CO_2 in the occupied period.

Table 5. Correlation coefficients between the CO_2 and PM concentrations for periods when the classrooms were occupied and for all period of measurements

Parameters	Period	School A		School B	
		H	NH	H	NH
CO_2 and PM_{10}	Occupied	0.64	0.73	0.79	0.69
	All	0.39	0.77	0.72	0.63
CO_2 and $PM_{2.5}$	Occupied	n/a	0.76	0.88	0.77
	All	n/a	0.80	0.79	0.72

CONCLUSION

Problems with indoor air quality in educational institutions are well known in all countries. The concentrations of PM, CO_2 and NO_2 measured in these two primary schools during heating and non-heating period were in line with other studies in Europe. Our results, as well as findings from earlier studies of other researchers, clearly show that levels of particulate matter and carbon dioxide in schools were high, especially in periods when classrooms were occupied. The high carbon dioxide concentrations were detected not only in the old school buildings, but also in the new schools. Concentrations of CO_2 higher than 1000 ppm were regularly detected in the classrooms during teaching hours. In school in urban area highest values of CO_2 were about 2200 ppm, while highest values of CO_2 were about 4500 ppm in school in rural area. CO_2 is a useful proxy for the estimation of ventilation rates and the dilution of pollutants with indoor sources and the improvement of perceived IAQ. The values of ventilation rates were lower than recommended values for school classrooms. It is likely that in the foreseeable future lower levels of daily mean concentrations of CO_2 during the school days will be implemented.

This study shows that the measurements revealed considerable differences and relationships not only between indoor and outdoor air qualities in two schools, but also between indoor concentrations in different classrooms in same school. The difference in PM and CO_2 concentrations in different seasons is mostly due to the different ventilation practices in heating and non-heating period.

The analysis of measuring results showed high correlation between the PM and CO_2 concentrations, not only for the period when children are in classrooms, but for the whole period of measurement.

Presented data was sufficient to indicate the need to improve the ventilation and cleaning practice in the selected schools. This study demonstrates a solid base for implementation of fresh air supply strategy in naturally ventilated schools and for design the further investigations toward the better indoor air quality in schools.

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NAUČNI RAD

KONCENTRACIJE ODABRANIH ELEMENATA U TRAGOVIMA U VAZDUHU I U LISTOVIMA DIVLJEG KESTENA U BEOGRADU

Kvalitet vazduha u unutrašnjem prostoru (IAQ) je veoma važan za zdravlje i dobrobit dece, pošto su deca posebno ugrožena i osetljiva na prisustvo zagađivača u vazduhu. Studija je sprovedena u dve prirodno ventilisane škole koje se nalaze u istoj opštini. Prva škola se nalazi u urbanoj sredini, u rezidencijalno-industrijskoj lokaciji, dok se druga škola nalazi u ruralnom području. Školske zgrade su odabrane na osnovu karakteristika urbane sredine. Merenja su vršena u grejnom i negrejnom periodu u trajanju od pet uzastopnih radnih dana. Cilj studije je bio da se analizira IAQ u učionicama sa posebnim naglaskom na nivoe i dnevne varijacije frakcija grubih i finih čestica (PM_{10} i $PM_{2.5}$), ugljen-dioksida (CO_2) i azot -dioksida (NO_2) tokom prisustva dece u učionicama i u periodu kada su učionice bile prazne. U ovom radu, koncentracija CO_2 je merena u učionicama i u ambijentalnom vazduhu u neposrednoj blizini škole. Koncentracije CO_2 veće od 1000 ppm često su se beležile u učionicama tokom nastave. Koncentracije PM_{10} u učionicama nisu prelazile vrednosti 50 $\mu g/m^3$ koja je preporučena vrednost Svetske zdravstvene organizacije. Koncentracije $PM_{2.5}$ su premašile preporučene vrednosti od 25 $\mu g/m^3$, u obe škole tokom perioda grejanja. Koncentracije NO_2 nisu premašile vrednost od 200 $\mu g/m^3$ što je preporučena vrednost. Ventilacija je izračunata i upoređena sa propisanim granicama. U oba perioda, tokom prisustva i odsustva dece u učionicama, uočena je visoka korelacija između CO_2 i PM.

Ključne reči: unutrašnji kvalitet vazduha (IAQ), čestice, ugljen-dioksid, azot-dioksid.